

A THEORETICAL ESTIMATE OF DRAFT VELOCITIES IN A SEVERE THUNDERSTORM

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ABSTRACT

Small scale surface divergence in the vicinity of a severe thunderstorm and an assumed distribution of divergence with height are used with the mass-continuity relationship to yield vertical velocity. In the case studied a maximum updraft of 218 ft. sec.⁻¹ and a maximum downdraft of 143 ft. sec.⁻¹ are computed.

1. INTRODUCTION

The Thunderstorm Project [1] has measured the magnitude of vertical motions in thunderstorms by growth of radar echoes and by displacement of aircraft in flight. Updraft velocities as great as 85 ft. sec.⁻¹ and downdraft velocities as great as 79 ft. sec.⁻¹ were evaluated. However, the storms sampled by the Thunderstorm Project were generally not severe,¹ and the magnitude of draft velocities in severe thunderstorms must be estimated indirectly.

Vertical motion, including draft velocities, can be computed by the mass-continuity relationship, using suitable values of horizontal velocity divergence integrated through a column. In order to obtain realistic values of the vertical motions in thunderstorms, however, the divergence must be computed for an area whose size is similar to that covered by the thunderstorm itself. Surface divergence on this scale can be computed from micro-networks of stations, such as used by the U.S. Weather Bureau's Thunderstorm Project and Cloud Physics Project. However, the lack of micro-scale wind observations aloft prohibits any computation of small-scale divergence above the surface, and some assumed distribution of divergence with height is required in order to estimate the draft velocities.

The case to be presented occurred over the surface micro-network of the U. S. Weather Bureau's Cloud Physics Project, Wilmington, Ohio, on March 19, 1948. The squall-line thunderstorms were locally severe with surface wind speeds in excess of 78 m.p.h. (limit of the wind speed recorders), and damage occurred to a number of farmsteads in the path of the storms. A description of some of the features of this case has been reported in a previous paper [2]. A micro-scale synoptic chart, showing the position of the squall line and a micro-Low at 1400

EST, is shown in figure 1. It is felt that this storm was of considerably greater severity than any sampled by the Thunderstorm Project aircraft. Estimates of the draft velocities should, therefore, be of interest.

2. ASSUMPTIONS

The theoretical estimates made in this study are based on the assumptions that:

(1) Divergence at the surface is compensated by divergence of the opposite sign aloft. Compensation due to surface pressure changes is assumed to be negligibly small.

(2) Mass divergence at the 12-km. level is of equal magnitude and opposite sign to that at the surface. The choice of the 12-km. level is somewhat arbitrary. It was chosen since 12 km. is a level at which the top of the thunderstorm might be found.

(3) The distribution of mass divergence from the surface to the 12-km. level conforms to a cosine curve in the interval 0 to π , i.e.:

$$(\text{Div}_2 \rho \mathbf{V})_z = (\text{Div}_2 \rho \mathbf{V})_0 \cos \left(\frac{\pi z}{12} \right) \quad (1)$$

where Div_2 is the horizontal divergence operator, ρ is density, z is height, \mathbf{V} is wind velocity, subscript z designates a value at any height z ($0 \leq z \leq 12$ km.), and subscript 0 at the surface. The choice of this distribution is somewhat arbitrary, too. A similar assumption was made by Beebe and Bates [3], although a lower height was used, and velocity divergence rather than mass divergence was considered.

(4) The vertical motion field depends completely upon the divergence field, regardless of the conditions that cause the vertical motion.

(5) In the mass-continuity equation, the local change in density with respect to time is negligibly small. The mass-continuity equation then is:

¹The U.S. Weather Bureau defines a severe thunderstorm as one in which surface wind gusts of 75 m.p.h. or greater, surface hail $\frac{3}{4}$ inch in diameter or greater, extreme turbulence, and/or tornadoes occur.

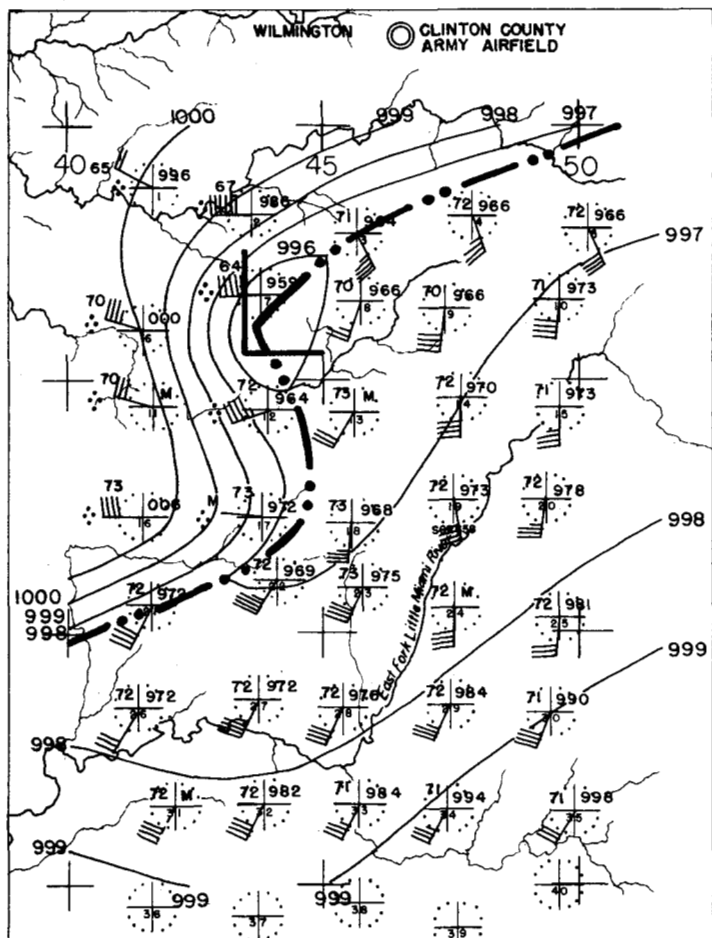


FIGURE 1.—Micro-synoptic surface chart for 1400 EST, March 19, 1948. Note the position of the squall line and micro-Low.

$$-\frac{\partial(\rho w)}{\partial z_i} \simeq \text{Div}_2 \rho \mathbf{V} \quad (2)$$

where w is the vertical component of motion.

Substituting from (1) yields:

$$\frac{\partial(\rho w)}{\partial z} \simeq -(\text{Div}_2 \rho \mathbf{V})_0 \cos\left(\frac{\pi z}{12}\right) \quad (3)$$

(6) The advection of density at the surface and the vertical motion at the surface are negligibly small. The integration of equation (3) between the limits 0 and z then yields

$$w_z \simeq -\frac{12\rho_0}{\pi\rho_z} (\text{Div}_2 \mathbf{V})_0 \sin\left(\frac{\pi z}{12}\right) \quad (4)$$

3. COMPUTATIONS

Equation (4) was used to compute the draft velocities w_z in the severe thunderstorm of March 19, 1948. Computations were made at 1-km. vertical intervals; i.e., $z=0, 1, 2, \dots, 12$. Values of ρ_z were taken from tables

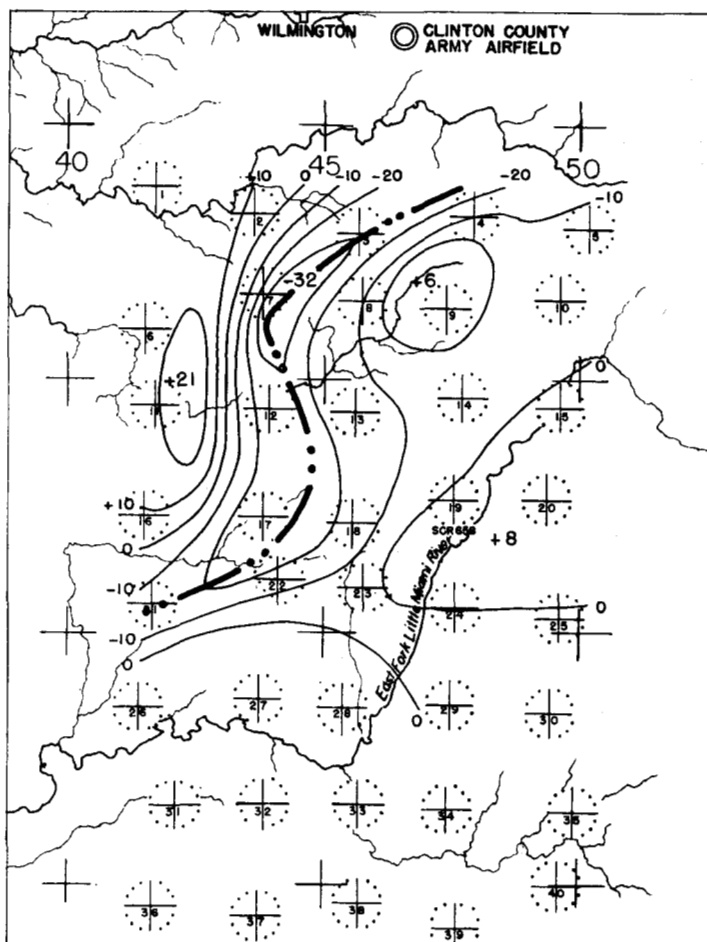


FIGURE 2.—Divergence computed from the wind field for 1400 EST, March 19, 1948. The position of the squall line is shown as a heavy solid line. Isolines of divergence are labeled in units of hr^{-1} . Note the intense center of convergence along the micro-wave of the squall line and the intense center of divergence west of the squall line.

of the standard atmosphere. Values of the surface velocity divergence were computed for selected grid position directly from the components u and v of the wind field according to the relationship:

$$(\text{Div}_2 \mathbf{V})_0 = \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)_0 \simeq \left(\frac{\Delta u}{\Delta x} + \frac{\Delta v}{\Delta y}\right)_0 \quad (5)$$

where the finite intervals Δx and Δy were taken as 2 miles. This is the approximate spacing of stations on the micro-network.

Values of the surface velocity divergence for 1400 EST are shown in figure 2. A minimum value of divergence (maximum value of convergence) of -32.0 hr^{-1} was computed just ahead of the squall line between stations 2, 3, 7, and 8; and a maximum value of divergence of 21.0 hr^{-1} was computed behind the squall line between stations 6,

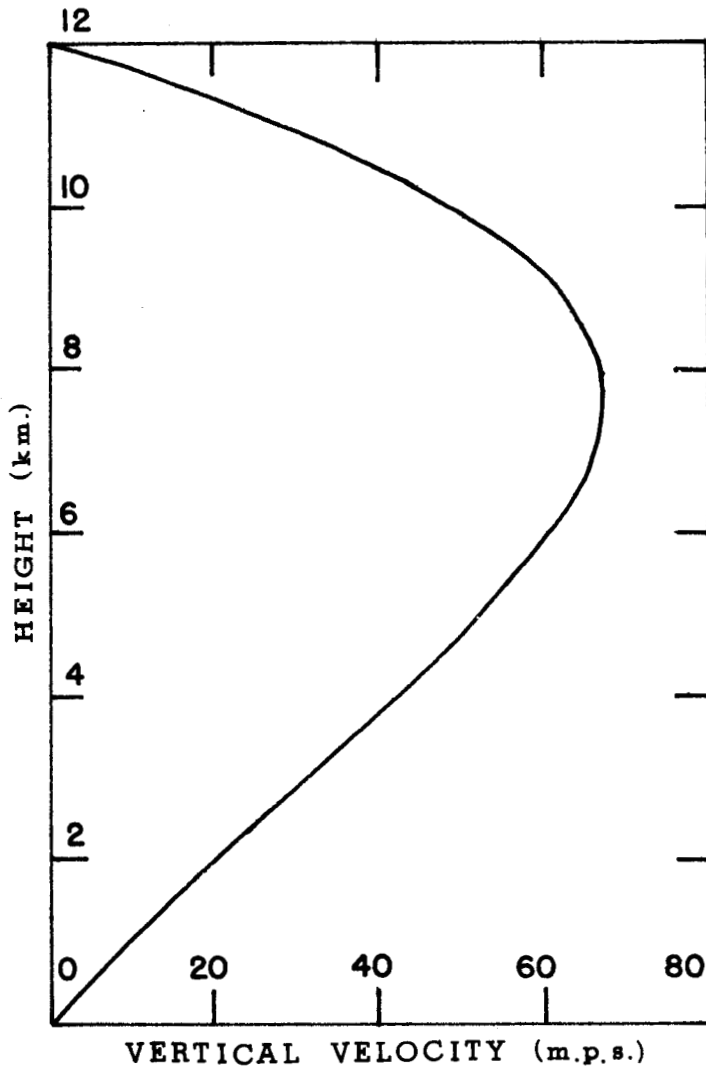


FIGURE 3.—Vertical profile of updraft velocities over a point located between stations 2, 3, 7, and 8 at 1400 EST, March 19, 1948.

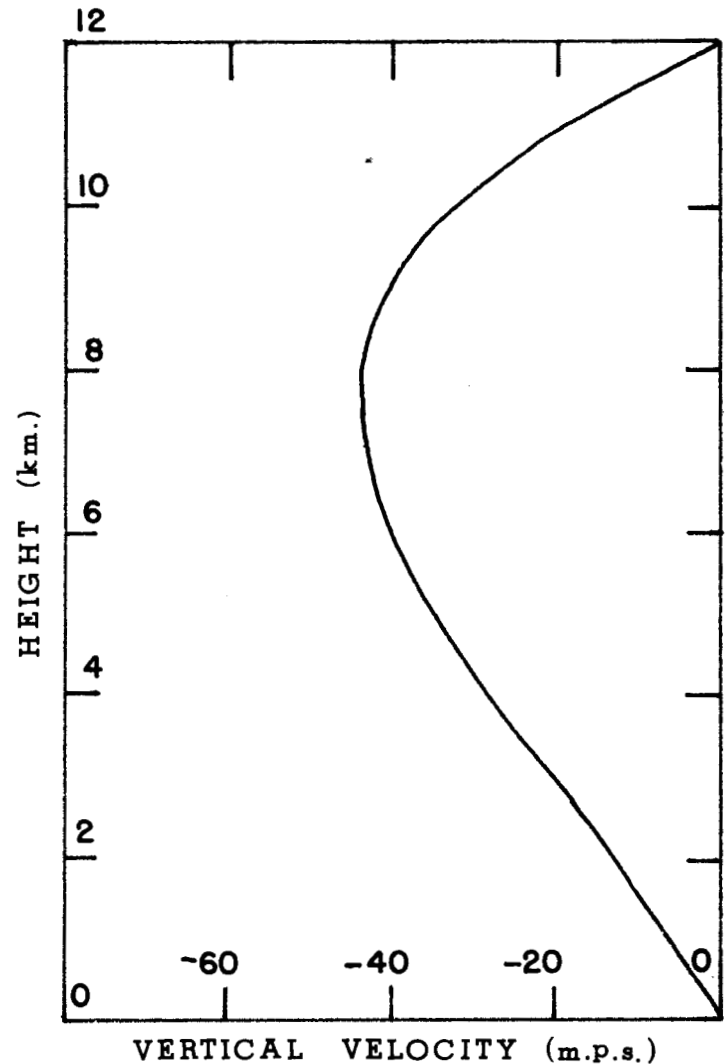


FIGURE 4.—Vertical profile of downdraft velocities with height over a point located between stations 6, 7, 11, and 12 at 1400 EST, March 19, 1948.

7, 11, and 12. These two values were used in the vertical velocity computations.

4. DRAFT VELOCITIES

Substituting the minimum value of divergence, -32.0 hr^{-1} , in equation (4) yields values of upward vertical motion that are shown graphically in figure 3. Substituting the maximum value of divergence, 21.0 hr^{-1} , yields values of downward vertical motion that are shown graphically in figure 4. Maximum draft velocities occurred at the 8-km. level. Maximum updraft was 66.5 m.p.s. (149 m.p.h. or 218 ft. sec. $^{-1}$). Maximum downdraft was 43.7 m.p.s. (98 m.p.h. or 143 ft. sec. $^{-1}$).

Computed drafts for this case are up to $2\frac{1}{2}$ times greater than the maximum updraft of 84 ft. sec. $^{-1}$ and maximum downdraft of 79 ft. sec. $^{-1}$ evaluated by the Thunderstorm Project [1]. The difference may be accounted for, at least in part, by the fact that thunderstorms of lesser severity were sampled by the Thunder-

storm Project (e.g., maximum convergence computed by the Thunderstorm Project was -20.0 hr^{-1} , as compared to -32.0 hr^{-1} computed for the March 19, 1948 case) and the probability that the severest of these may not have been sampled during their brief periods of greatest severity (e.g., in the March 19, 1948 case, the convergence of -32.0 hr^{-1} existed for only a few minutes; values 5 minutes before and after this maximum were -20.0 hr^{-1} or less). Because of the limitations in sampling by the Thunderstorm Project, the computations above may be fairly representative of values in severe thunderstorms.

Aside from this, some errors undoubtedly exist in the computations just presented. Most serious, probably, is the assumed distribution of divergence with height. It may be noted that a lowering of the height of the upper divergence level would decrease draft velocities, while a raising of this height would increase them. A departure of the distribution from a cosine curve would greatly affect the velocities, and could either increase or decrease

them. Because of assumptions (2) and (3) the values obtained should be considered only as crude estimates. It is hoped that future research may be able to ascertain more exactly the draft velocities occurring in severe thunderstorms.²

² According to a pilot report at 1910 GMT on October 10, 1958, a U.S. Air Force pilot encountered extreme turbulence and heavy hail over Watertown, N.Y. The aircraft, a C-47, went from 6,000 to 10,000 feet in 30 seconds. This updraft of 8,000 ft. min.⁻¹ or 133 ft. sec.⁻¹ is about 1½ times greater than any encountered by the Thunderstorm Project and is 61 percent of the theoretical value computed above.

REFERENCES

1. H. R. Byers and R. R. Braham, *The Thunderstorm*, U.S. Weather Bureau, Washington, D.C. 1949, 282 pp. (pp. 40, 53, 130).
2. D. T. Williams, "A Surface Micro-Study of Squall-Line Thunderstorms," *Monthly Weather Review*, vol. 76, No. 11, Nov. 1948, pp. 239-246.
3. Robert G. Beebe and Ferdinand C. Bates, "A Mechanism for Assisting in the Release of Convective Instability," *Monthly Weather Review*, vol. 83, No. 1, Jan. 1955, pp. 1-10.

CORRECTION

Vol. 86, September 1958, p. 133: In the caption the time for figure 1B should read "1200 GMT, May 27, 1958."